CEDIM FDA-Report No. 1 on Hurricane *Sandy* 22-30 Oct. 2012

- Information as of 30 Oct. 2012, 18 UTC -

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1 Hazard Information

1.1 Summary

From October 22, until October 29, 2012, hurricane *Sandy* made its way from the Caribbean Sea into the Atlantic Ocean and finally entered the United States on early October 30, not far from New York. According to the Saffir Simpson Hurricane Scale, *Sandy* was a category 2 hurricane. Along its path *Sandy* caused many fatalities on Jamaica and Cuba and left many homeless. The interaction between *Sandy* and an extra-tropical weather system created a huge storm that made landfall on the U.S. east coast and affected large areas; it brought high impact weather as far as to the Great Lakes and even southern and southeastern Canada. Due to its extension and intensity and due to the expected massive damage and loss in the densely populated New England states *Sandy* in some media was named *Frankenstorm*.

1.2 Evolution of hurricane *Sandy*

Sandy was added to the list of 2012 hurricanes on October 22, it was tropical storm system #18 so far this year in the North Atlantic region. Huge convective cloud structures began to organize 250 km north of Panama. While further strengthening, *Sandy* was classified a category 1 hurricane on October 24, just before crossing the island of Jamaica. Heading north, the hurricane approached Cuba, where the storm center arrived 24 hours later. Associated with heavy rain, *Sandy* crossed the eastern portion of Cuba by reaching its maximum intensity. Between 06 and 12 UTC on October 25, the hurricane had 1min-sustained winds of 95 kt (176 km/h) and gusts around 110 kt (204 km/h) making *Sandy* a category 2 hurricane.

Constant in intensity, *Sandy* passed the Bahamas on October 26. The following day, the hurricane made a right turn towards the northeast and started to loose strength. More and more forecast models began to predict a scenario where *Sandy* was expected to make landfall at the east coast of the U.S. Even time and location of landfall turned out to be already pretty consistent, the hurricane was expected to arrive in the night of October 29-30 somewhere along the Delaware/New Jersey Atlantic coast.

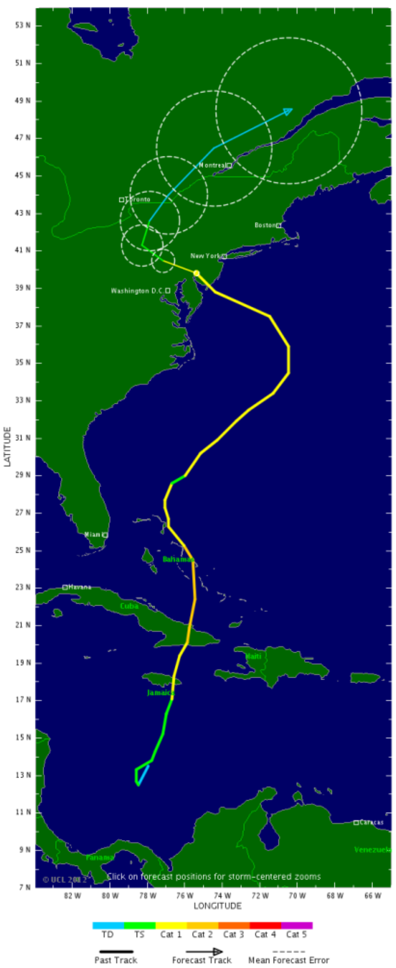

Figure 1: Track of hurricane *Sandy.* Image Credit: tropicalstormrisk.com

Some hours before entering the U.S. mainland, the hurricane intensified again and showed mean wind speed of 80 kt (148 km/h). The storm center itself crossed the coastline around 00 UTC on October 30.

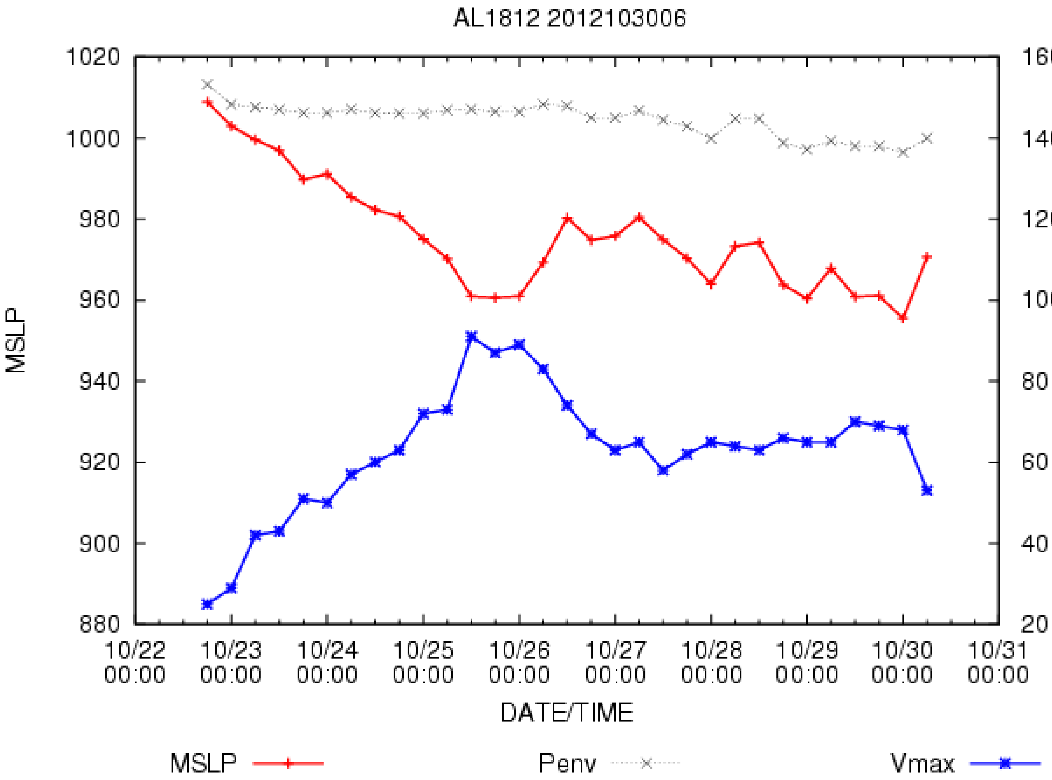

Figure 2: Mean sea level pressure (in storm center) and maximum winds of *Sandy.* Image Credit: http://rammb.cira.colostate.edu

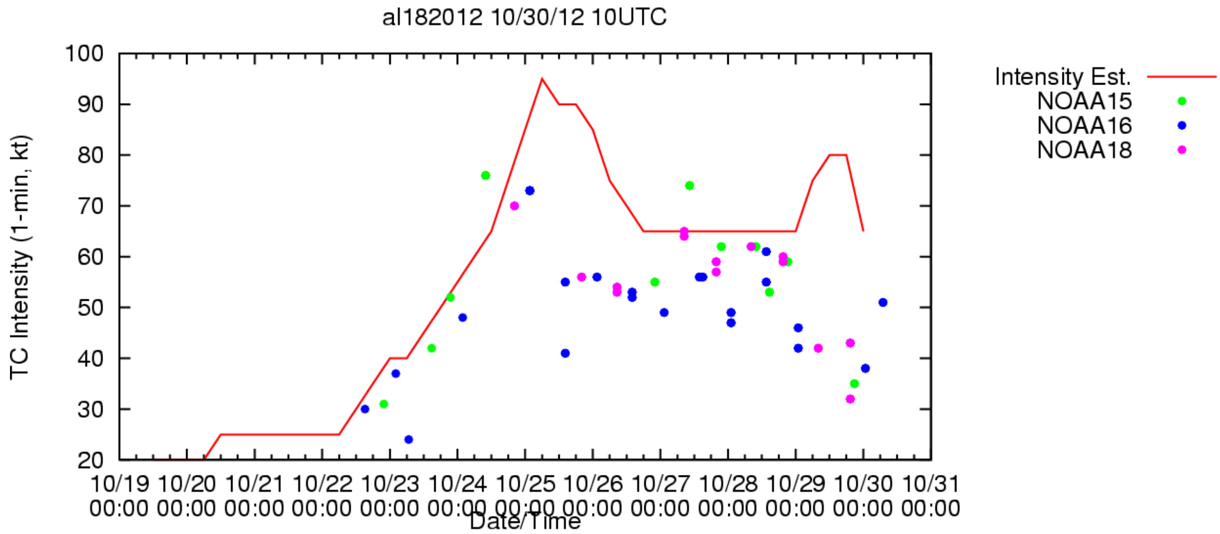

Figure 3: Time series of the storm intensity of *Sandy* as received by satellite observations. Image Credit: http://rammb.cira.colostate.edu

1.3 Affected areas, wind, precipitation, and tides

Before making landfall in the U.S., the extension of *Sandy* grew rapidly. Even far from the center storm force winds occurred. Due to the interaction with a large upper level trough that stretched across the central portion of the U.S., and due to cold air advection that got involved into the low-level circulation of the storm system, *Sandy* lost its tropical characteristics and turned into an extra-tropical system. Cloud and precipitation areas covered most of the northeastern parts of the U.S. from October 29 afternoon onwards. Many parts between the Atlantic coast and the Great Lakes experienced wind gusts of 75 km/h or even more. The JFK airport at New York City (NYC) recorded a wind gust of 128 km/h.

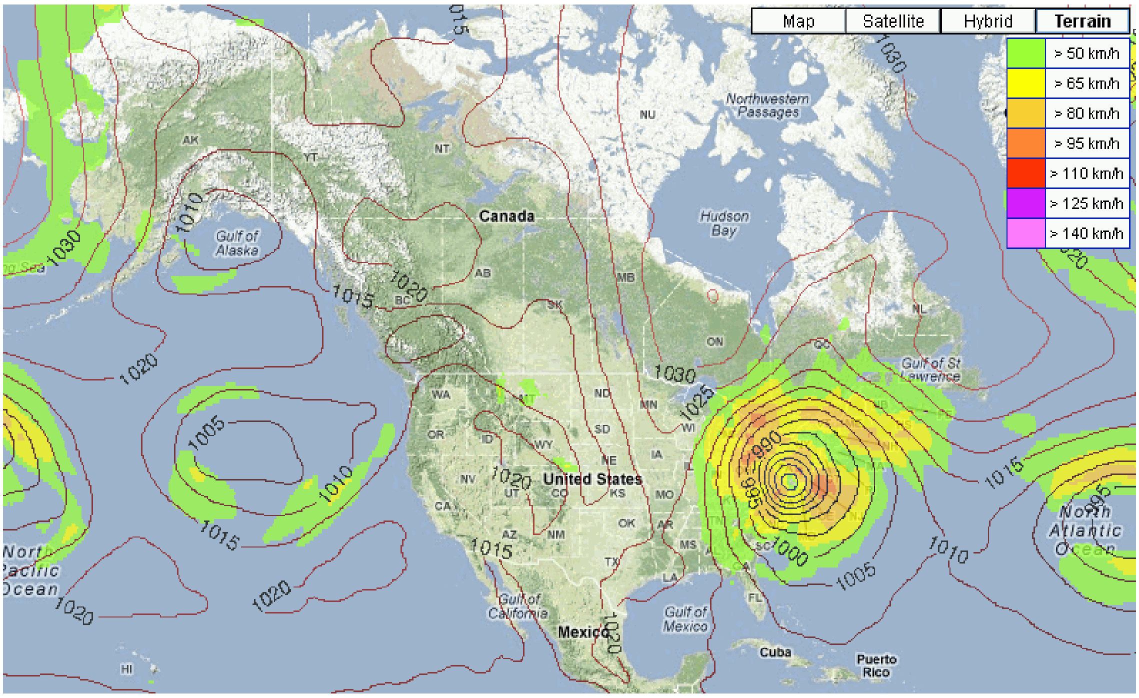

Figure 4: Wind peak gusts on October 30, 2012, 06 UTC (GFS-model run).
Image Credit: wettergefahren-fruehwarnung.de

While strong storm surge along the coastlines of Virginia, Delaware, New Jersey and New York caused severe problems to coastal highways and other kinds of infrastructure, heavy precipitation was responsible for flooding and high river levels elsewhere. Wallops Island in Virginia got a rain amount of 214 mm within 48 hours, Baltimore/Washington Int. Airport recorded 150 mm (see Figures 5-7).

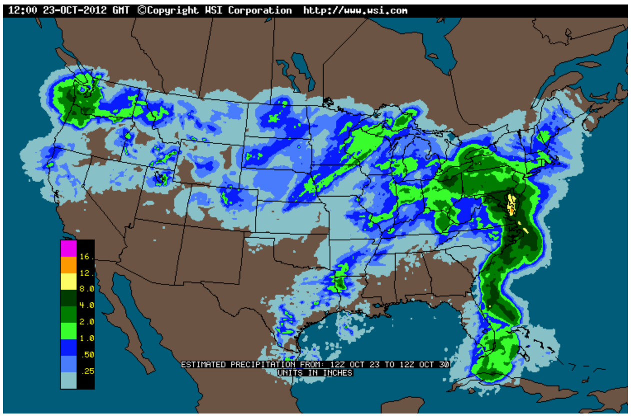

Figure 5: Precipitation amount (radar), Oct 23-30, 12UTC
Image Credit: intellicast.com

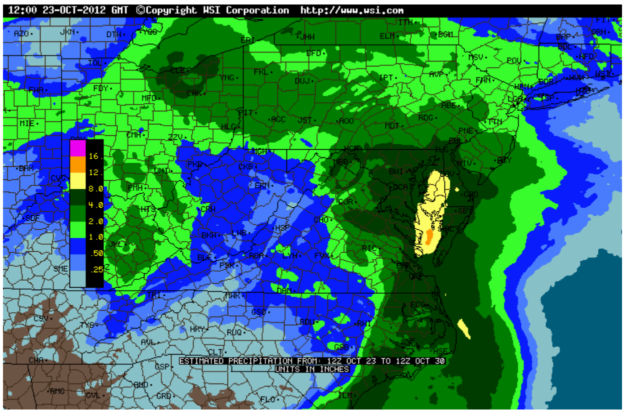

Figure 6: Precipitation amount (radar), Oct 23-30, 12UTC
Image Credit: intellicast.com

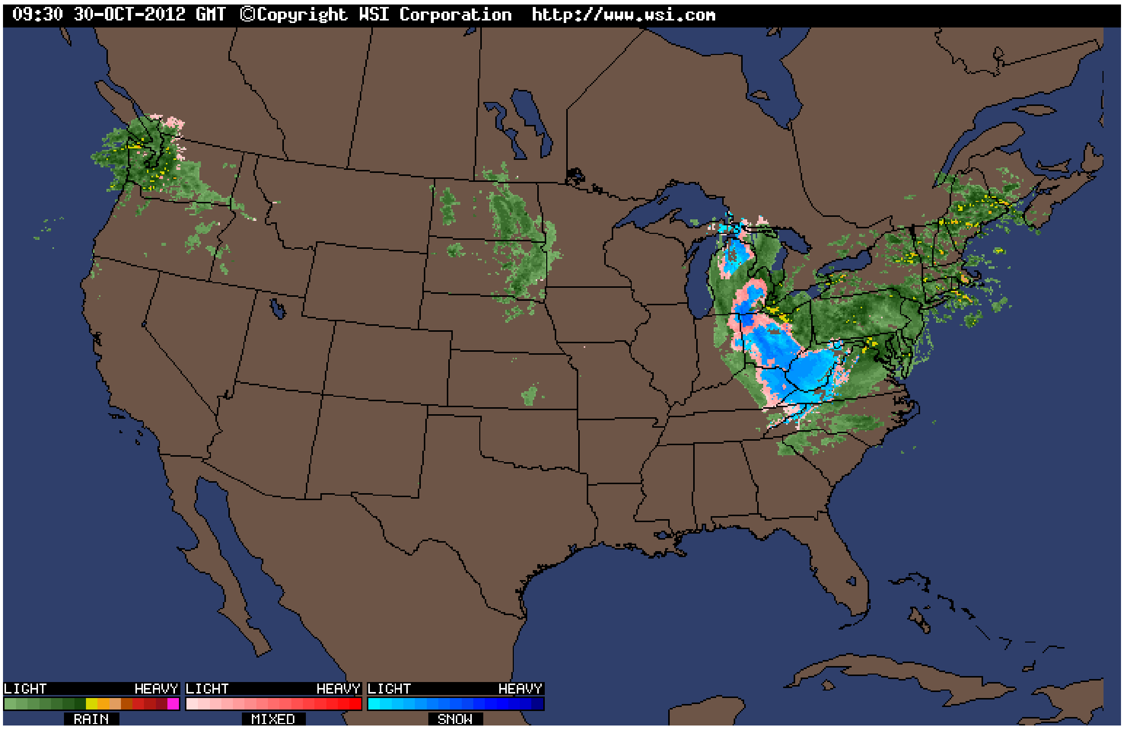

Figure 7: Radar image, October 30, 2012, 09:30 UTC
Image Credit: intellicast.com

Pennsylvania, Maryland, New Jersey, Delaware and Virginia received a rain amount between 100 and 200 mm. According to radar data, the maximum value exceeded 300 mm in a small area in the vicinity of Chesapeake Bay.

The intrusion of cold air near the surface from the northwest led to heavy snowfall especially in the southern and central Appalachian Mountains. In mountainous areas of Tennessee, Kentucky, North Carolina, West Virginia and Virginia, snow amounts of more than 50 cm have to be taken into account.

1.4 *Sandy* on satellite images

Figure 8 is a satellite image showing *Sandy* just crossing Jamaica. At this time, *Sandy* is a category 1 hurricane already. Figure 9 shows *Sandy* with its storm center well off the coast. A huge shield of mainly high level clouds covers most of the northeastern parts of the U.S. already, indicating the beginning of the interaction with an upper level trough to the west.

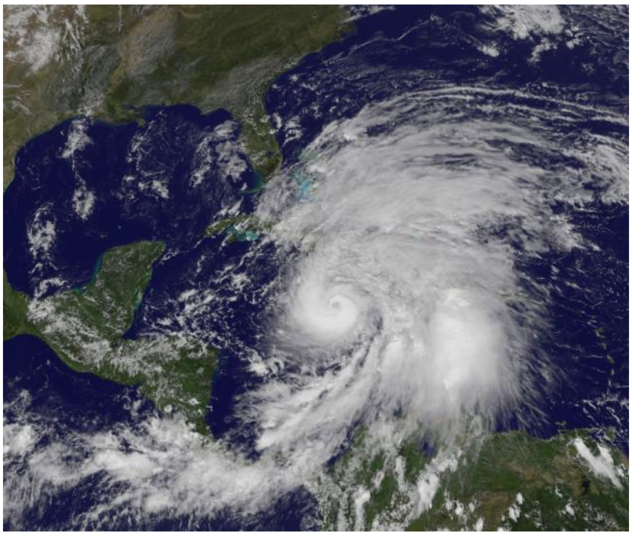

**Figure 8: Satellite image, October 24, 2012, 18:15 UTC,
Image Credit: NASA GOES Project**

**Figure 9: Satellite image, October 28, 2012, 17:45 UTC
Image Credit: NASA GOES Project**

1.5 Secondary hazards

In the course of storm *Sandy,* humid air masses of tropical origin were advected to the land. High amounts of precipitation are expected in the states of Delaware, New Jersey, Washington D.C., Maryland, northeast of Virginia as well as in the south of Pennsylvania. In view of the precipitation amounts forecasted (over 100 mm in 24 hours), there is a considerable potential for the occurrence of pluvial and fluvial floods.

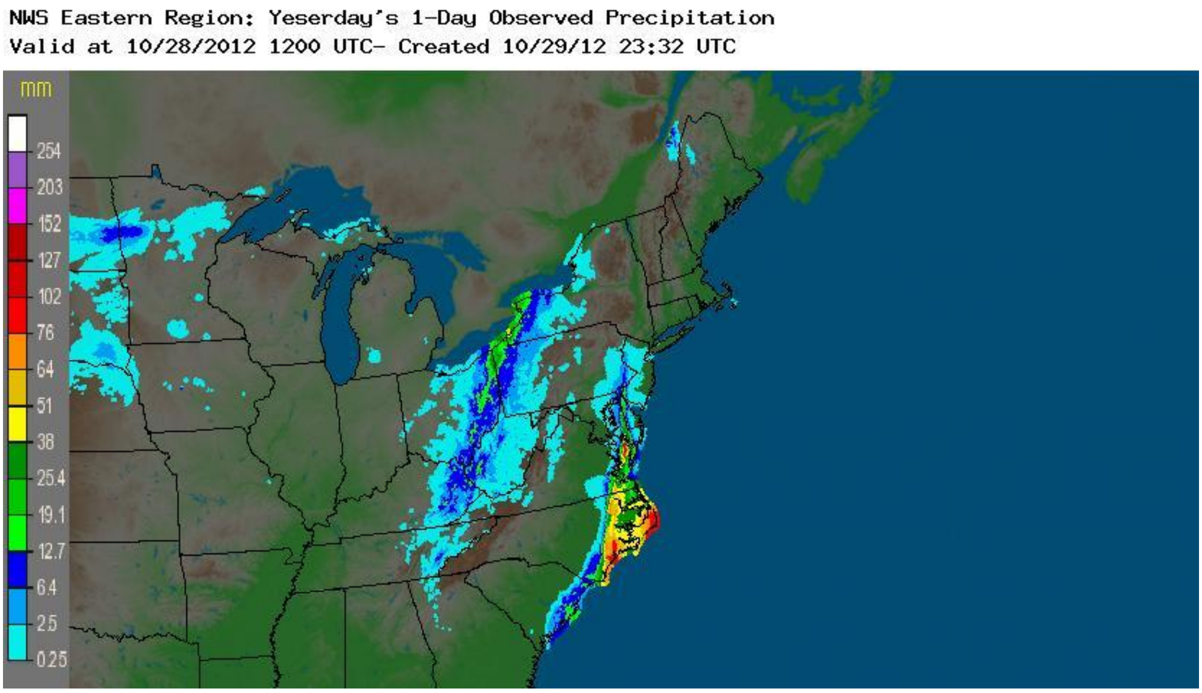

Figure 10: Observed precipitation on October 28th 2012 (Source: National Weather Service, http://water.weather.gov/precip)

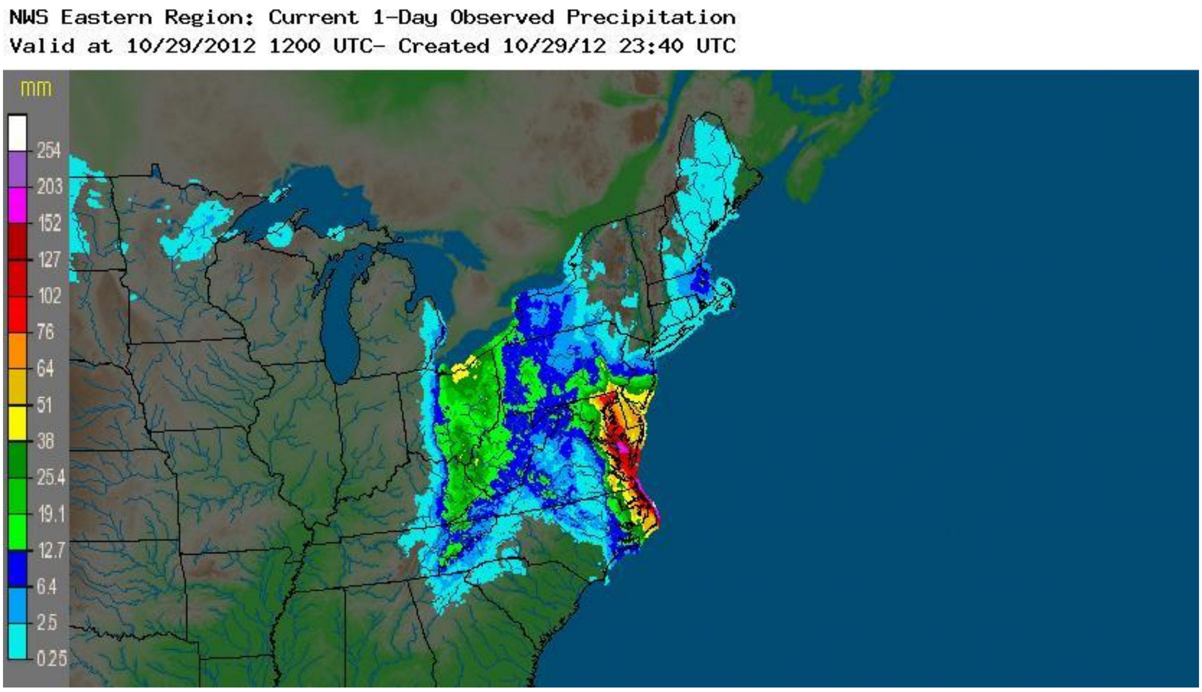

Figure 11: Observed precipitation on October 29th 2012 (Source: National Weather Service, http://water.weather.gov/precip)

Observed daily amounts of precipitation[1] on October 28th and 29th 2012 provided by the National Weather Service (http://water.weather.gov/precip) for the NWS Eastern region of the USA are shown in Figures 10 and 11.

The precipitation field in the region extends over the states of North Carolina, Virginia, Maryland, Delaware, New Jersey, Pennsylvania, New York, Ohio, West Virginia, the western part of Tennessee as well as the northern parts of Gerogia and South Carolina. This corresponds to an area of approx. 1,000.000 km². However, the core area of extreme precipitation observed on October 29 extends along the east coast over a length of approximately 500 km affecting the states of North Carolina, Virginia, Maryland and Delaware. In this area, precipitation amounts in the range of 100 mm up to 152 mm in 24 hours as indicated. Depending on the location, this corresponds to a 24 hour rainfall with a return period of approx. 50 to 100 years (USDA 1986). The precipitation field has been derived from WSR-88D NEXRAD data which have been compared and bias-corrected using surface-based rain gauges (Seo, 1998; Seo, Breidenbach and Johnson, 1999; Seo and Breidenbach, 2002).

The current implication of the precipitation load in terms of fluvial flooding is illustrated in Figure 13. It shows the water level gauges in state of flooding on October 30 for the whole area of the U.S. The main region of gauges reporting flooding is located in the Mid Atlantic hydrological region[2] covering the states of Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York and Vermont.

In total, there are 8 gauges reporting major flooding or moderate flooding, respectively. 29 gauges are classified to the state of minor flooding according to the predefined alert levels based on property damage and public threat[3].

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1 "Observed" data is a byproduct of National Weather Service (NWS) operations at the 12 CONUS River Forecast Centers (RFCs), and is displayed as a gridded field with a spatial resolution of roughly 4x4 km². "Observed" data is expressed as a 24-hour total ending at 1200 Z.

2 Mid Atlantic Region: The drainage within the United States that ultimately discharges into: (a) the Atlantic Ocean within and between the states of New York and Virginia; (b) Long Island Sound south of the New York-Connecticut State Line; and (c) the Riviere Richelieu, a tributary of the St. Lawrence River. Includes all of Delaware and New Jersey and the District of Columbia, and parts of Connecticut, Maryland, Massachusetts, New York, Pennsylvania, Vermont, Virginia, and West Virginia.

3 Definition of NWS flood classes: Minor Flooding: minimal or no property damage, but possibly some public threat or inconvenience. Moderate Flooding: some inundation of structures and roads near streams. Some evacuations of people and/or transfer of property to higher elevations are necessary. Major Flooding extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.

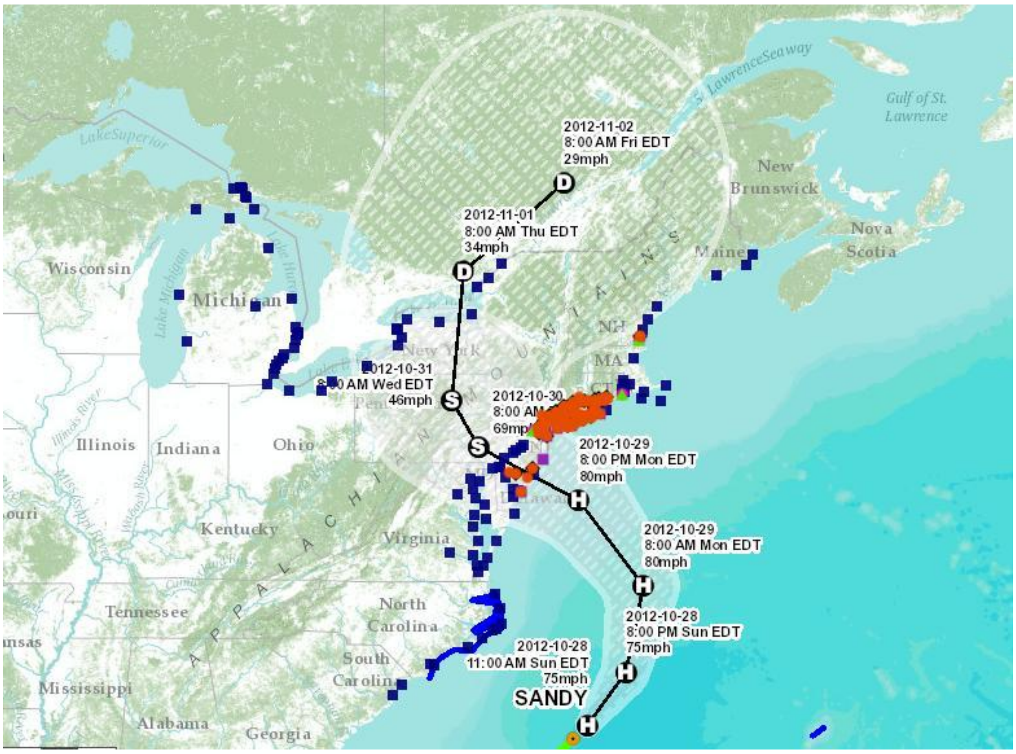

Figure 12: USGS Storm Tide Mapper, 30 Oct. 2012, 10:13 CET. (http://www.usgs.gov/blogs/features/files/2012/10/Figure-11.jpg)

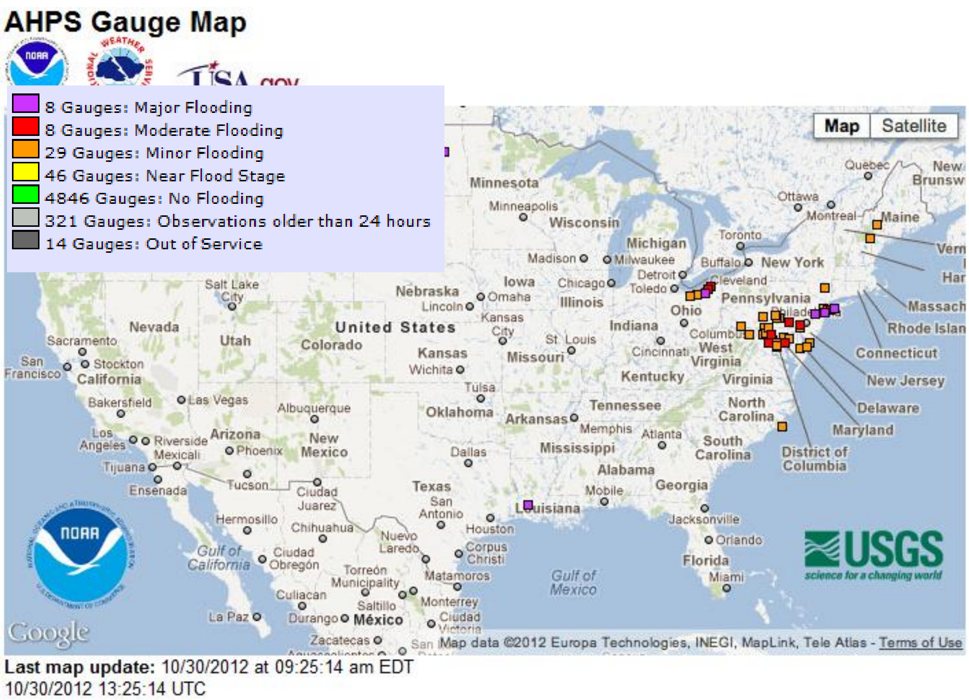

Figure 13: Classification of USGS/ NOAA water level observations for gauge locations in flood on October 30th 2012 in the USA (Source: National Weather Service) (http://water.weather.gov/ahps/index.php?current_color=flood&current_type=all&fcst_

type=obs&conus_map=d_map#)

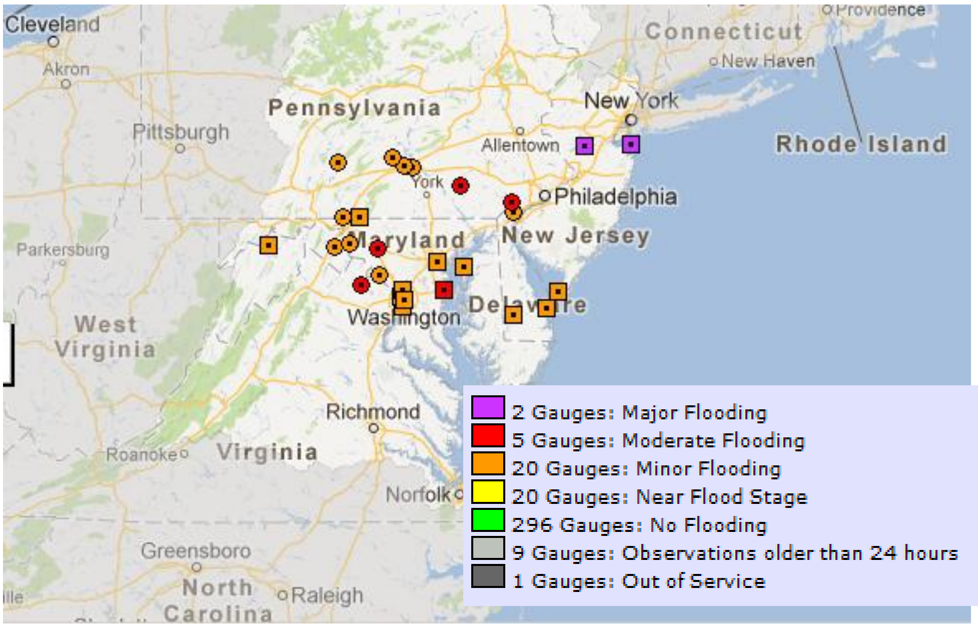

Figure 14: Classification of USGS/ NOAA water level observations for gauge locations in flood on October 30th 2012 in the Mid Atlantic hydrological region (Source: http://water.weather.gov/ahps/region.php?wrr=2&fcst_timeframe=336&current_color=flood&current_type=all&fcst_type=obs&conus_map=d_map&center_point_lat=41.14557&center_point_lon=-75.82763599999998&default_zoom=6&map_type=roadmap)

Table 1: Summary of recent flood and high flow conditions at the gauges reporting flooding in the Mid Atlantic hydrological region. This compilation also provides a classification with regard to historic flood events. The rank indicates the magnitude of the current peak in comparison to other observed flood events.

USGS station number	USGS station name	Drain. area [mi²]	NWS flood stage [ft]	No. of days above flood stage	NWS flood class	Highest peak from 2012-09-29 to 2012-10-30				Historical Peaks	
						Date	Stage [ft]	Stream flow (date) [ft³/s]	Rank	No. of years	Max. (year) [ft³/s]
1359139	HUDSON RIVER AT ALBANY NY	8288	11	1		30.10.2012	11.3	–	–	–	–
1372058	HUDSON RIVER BELOW POUGHKEEPSIE NY	11740	5	2		30.10.2012	9.5	–	–	–	–
1387450	Mahwah River near Suffern NY	12.3	4	1		02.10.2012	4.25	252	47	52	1840 1977
1390450	Saddle River at Upper Saddle River NJ	10.9	4	1		04.10.2012	4.65	1560	20	45	6290 1999
1472198	Perkiomen Creek at East Greenville, PA	38	4	3		29.10.2012	5.43	2670	18	30	6740 1984
1477000	Chester Creek near Chester, PA	61.1	8	2		29.10.2012	10.54	3840	30	80	21000 1971
1478000	CHRISTINA RIVER AT COOCHS BRIDGE, DE	20.5	10.5	2		29.10.2012	12.35	1840	36	69	7780 2011
1479000	WHITE CLAY CREEK NEAR NEWARK, DE	89.1	13	2		29.10.2012	15.28	6710	10	72	19500 1999
1480000	RED CLAY CREEK AT WOODDALE, DE	47	7	1		29.10.2012	7.45	2390	34	70	15600 2003
1480015	RED CLAY CREEK NEAR STANTON, DE	52.4	15	2		29.10.2012	17	3360	11	23	17400 2003
1480300	West Branch Brandywine Creek near Honey Brook, PA	18.7	7	2		29.10.2012	9.43	2440	13	52	3800 1996
1480870	East Branch Brandywine Creek below Downingtown, PA	89.9	7	2		29.10.2012	11.12	4500	13	40	8160 1972
1481000	Brandywine Creek at Chadds Ford, PA	287	9	2		30.10.2012	12.19	9400	25	92	26900 1999
1487000	NANTICOKE RIVER NEAR BRIDGEVILLE, DE	75.4	8	1		30.10.2012	8.09	1140	16	70	3020 1979
1564512	Aughwick Creek near Shirleysburg, PA	301	10	1		30.10.2012	11.18	6800	15	22	44400 1996
1568000	Sherman Creek at Shermans Dale, PA	207	9	1		30.10.2012	9.52	8480	32	83	44000 1927
1570000	Conodoguinet Creek near Hogestown, PA	470	8	1		30.10.2012	8.1	6110	52	79	33700 1972
1571500	Yellow Breeches Creek near Camp Hill, PA	213	7	2		30.10.2012	8.61	3460	22	68	19300 1975
1576500	Conestoga River at Lancaster, PA	324	11	1		30.10.2012	14.18	13600	12	83	50300 1972
1599000	GEORGES CREEK AT FRANKLIN, MD	72.4	8	2		29.10.2012	8.64	2680	22	83	8500 1936
1601500	WILLS CREEK NEAR CUMBERLAND, MD	247	10	2		29.10.2012	10.27	9430	18	83	45900 1996
1604500	PATTERSON CREEK NEAR HEADSVILLE, WV	221	9	1		30.10.2012	9.59	3420	44	72	16000 1955
1614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	494	10	1		30.10.2012	10.32	7400	45	86	32400 1972
1616500	OPEQUON CREEK NEAR MARTINSBURG, WV	273	10	1		30.10.2012	11.32	4050	37	65	23400 1996
1619000	ANTIETAM CREEK NEAR WAYNESBORO, PA	93.5	7.5	1		30.10.2012	8.15	2820	6	26	5430 1972
1619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	281	8	2		30.10.2012	9.45	4930	17	85	12600 1956
1639000	MONOCACY RIVER AT BRIDGEPORT, MD	173	16	1		29.10.2012	16.01	11100	18	71	24400 1996
1642190	MONOCACY RIVER AT MONOCACY BLVD AT FREDERICK, MD	703	17.8	1		30.10.2012	21.98	21800	3	8	26500 2003
1643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	817	15	2		30.10.2012	18.86	22700	27	83	81600 1972
1644000	GOOSE CREEK NEAR LEESBURG, VA	332	12	1		30.10.2012	17.14	15800	17	85	78100 1972
1645000	SENECA CREEK AT DAWSONVILLE, MD	101	7.5	2		30.10.2012	11.12	8880	11	81	26100 1972
1647600	POTOMAC RIVER AT WISCONSIN AVE, WASHINGTON, DC	–	6	1		30.10.2012	6.26	–	–	–	–
1648000	ROCK CREEK AT SHERRILL DRIVE WASHINGTON, DC	62.2	7	2		30.10.2012	9.09	2610	17	82	12500 1972

2 Disaster Profile

2.1 Background

The affected area comprises the political center of the United States, Washington D.C., as well as the world's most important financial center (New York) which is also the biggest city and of the United States and the most populated region of the country, with approx. 20 Mio inhabitants living in the Metropolitan area of New York (see Figure 15). The affected area has particular economic relevance because of the metal/ steel industry and diverse manufacturing industries.

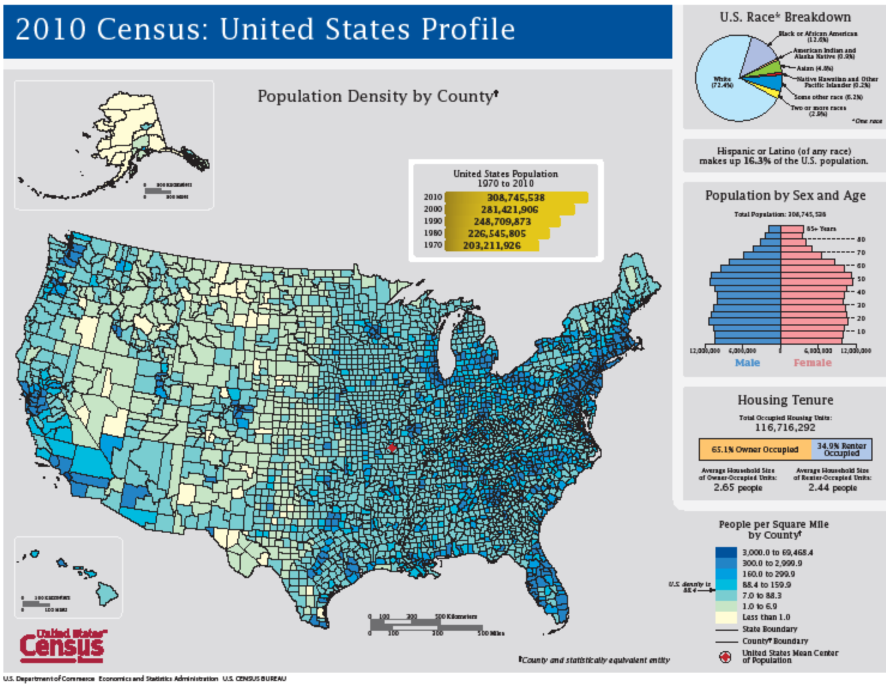

Figure 15: Population density by county

2.2 Geographical setting of the affected area

The area affected was the East Coast of the United States from North Carolina to Massachusetts, including New Hampshire (as of 30 Oct. 2012); Appalachian Mountains (Pennsylvania, New York State); Center/landfall most heavily affected: Delaware, New Jersey, New York (City).

<u>Shoreline characterization:</u>

The shoreline in the affected area consists of flat sandy barrier and drowned valley coasts with dunes. These coastal forms are interrupted by huge bays and inlets (from south to north: Pamlico Sound, Albemarie Sound, Chesapeake Bay, Delaware Bay, Long Island Sound, Buzzards Bay, Cape Cod Bay). Wetlands and marches often blur the clear distinction between land and sea. The whole coastline is extremely prone to coastal change by erosion and will undergo significant changes caused by hurricane *Sandy* (see USGS: http://coastal.er.usgs.gov/hurricanes/sandy/).

Coastal Plains:

The affected area is the northern part of the Atlantic Plain. The plain rises gently from the coastal areas to the Appalachian Mountains forming some terraces.

3 Loss and Damage Analysis

With high wind speeds, precipitation, flooding, storm surges (U.S. east coast), the storm system *Sandy* has impacted a wide region from the Caribbean to the East Coast of the U.S. One day before landfall of *Sandy* at the U.S. coast, the disaster modeling company Eqecat estimated economic loss from *Sandy* in the U.S. from $10 to $20 billion, thereof $ 5 to$ 10 billion insured losses. Latest news after landfall increased this estimation to $35 billion to $45 billion (ABC-news). Power outages and interruption of transportation lines in Metropolitan Areas of New York are expected to accumulate further indirect damages. 7 Million people are reported having no electricity supply.

3.1 People

Given the size of the affected area in the US and the population density in the eastern parts with 50 to 60 million people, almost on fifth of the U.S. population could be directly affected by *Sandy*, among them the approximately 20 million inhabitants of the Metropolitan Area of New York – Northern New Jersey and Long Island.

3.2 Fatalities and Casualties

According to current information, 86 people have lost their lives during *Sandy* (see Table 2). The current media attention is focused on U.S. east coast Metropolitan area, yet it should be recognized that 69 people already have died in the Caribbean from impacts of Hurricane *Sandy*. In the U.S.,16 fatalities have been reported in the states New Jersey, New York, Maryland, North Carolina West Virgina, Pennsylvania, and Connecticut. One person has been killed in Canada.

3.3 Health and healthcare impacts

Hospitals in the area took different measures to prepare and ensure their functionalities during *Sandy*. According to the Huffington Post, they checked their generators and water pumps, extended hours and set up beds for their staffs, canceled elective surgeries and in some cases moved patients to higher floors or even other nearby facilities, in some cases hospitals were even closed. Some hours after the landfall, the University Hospital of New York had to be evacuated due to problems with energy supply and the emergency generator.

Table 2: Victims related to storm *Sandy* since October 26th (Information ABC news as of 30.10.2012, 2 p.m. MEZ)

Country	No. of deaths
Jamaica	1
Haiti	52
Dominican Republic	2
Cuba	11
Puerto Rico	1
Bahamas	2
USA	16
Canada	1

3.4 Evacuation and Shelter - Preparation for the disaster

During the days before the expected landfall of *Sandy*, evacuation orders were issued, and shelter was prepared and provided throughout the potentially affected area. More than 500.000 people were told to evacuate from their homes in low lying areas (approx. 375.000 from New York, 66.000 from Atlantic City/ New Jersey and 66.000 from coastal communities in Delaware). In most cases the evacuation orders were mandatory.

It has been reported that in some places people did not follow evacuation orders, referring to the experience from Hurricane *Irene* the year before. Hurricane *Irene* hit the coasts with less severe impact than expected from the forecast, and the experience of an “unnecessary” evacuation might have been still very vivid in people’s memory leading them to stay at their homes. Unwillingness or inability to follow evacuation orders during disasters is a problem that has been very often observed also during major events.

3.5 Electric Power Outage

As of reports coming till 9:00 a.m. ET (13 UTC) on October 30, 2012 about 7 million customers in the Northeast of the United States are without power. Estimates of the population affected by blackouts as a result of the landfall of Hurricane *Sandy* are higher and are widely reported to be around 10 million; with people without power from West Virginia to Maine and even as far west as Chicago due to expected high winds and high waves on Lake Michigan. The power cuts are due to floods, flying debris from the storm and secondary effects such as explosions and fires at substations (e.g., 14th street and FDR drive in NYC); however, the majority of the affected power cuts are controlled and deliberate power cuts to avert further damage (if substations are flooded while in operation, the equipment will fail and need to be replaced) and to ensure quicker restoration. The underground power lines that deliver electricity in urban areas such as New York City are much less vulnerable to outages than overhead lines because they aren't exposed to wind and falling trees or branches. Although when they are exposed to damage from flood waters, they can be harder to repair because the equipment is more difficult to access.

The power outages shown in Table 3 here brings emerging information from diverse sources on the current and expected (based on modeled estimates) of power outages due to Hurricane Sandra and its secondary impacts. As the situation is changing on a quarter-hourly basis, at the time of this report it is not possible to provide an accurate overview of the overall power outages in the impacted region. Furthermore, the power outages shown here are based on reports at the time of this writing and do not reflect the duration of the outage or how long the affected population will remain without power.

Table 3: Power Outages Reported in Affected Northeast States

States	**Predicted Power Outages (Guikema, 2012a)**	**Reported Estimates by Utility Companies ***
Pennsylvania	4.8 million	897,100[10)]
New Jersey	3.5 million	2.1[7)] - 2.3 million[1)]
Delaware and Maryland	2.3 million	393,400[2)]
New York	1-3 million (possibly greater)	1.58 million[11)] - 1.8 million [1)]
Delaware	500,000	76,000
Washington, D.C.	260,000	24,000[1)]
Massachusetts	N/A	322,000[1)] – 369,856[4)]
Rhode Island	N/A	119,000[12)]
New Hampshire	N/A	52.200[6)] – 234,000[1)]
Maine	N/A	83,000[1)] – 90,800[5)]
Connecticut	N/A	494,000[3)]
North Carolina	N/A	16,900[8)]
Ohio	N/A	215,000[9)]
Vermont	N/A	9,400[13)]
Total Affected	11.3 – 19 million	~ 7 million

* CBS News/AP October 30th, 2012 1:35am ET**:** http://www.cbsnews.com/8301-201_162-57542015/hurricane-sandy-more-than-500k-already-without-power/

1) Multiple States: As of News reports coming in till Tuesday 8:00 am ET (Source: CNN)
2) Delaware and Maryland: Reports from Delmarva, BGE, PEPCA, Mon Power and Potomac Edison
3) Connecticut: Connecticut Light & Power: http://outage.cl-p.com/outage/outagemap.aspx
4) Massachusetts: Mass Star, Western Mass Electric Co. and Unitil and National Grid
5) Maine: Central Maine Power, Bangor Hydro
6) New Hampshire: Unitil and National Grid
7) New Jersey: Public Service Electric and Gas, Jersey Central Power & Light, Atlantic City Electric
8) North Carolina: Duke Energy and Progress Energy

9) Ohio: First Energy, Duke Energy, DP&L and South Central Power
10) Pennsylvania: Peco, FirstEnergy, PPL Electric Utilities
11) New York: LILCO, Cond Edison, NYSEG, National Grid
12) Rhode Island: National Grid
13) Vermont: Green Mountain Power

The widespread lack of power is one of the critical aspects emerging out of the event and may have far-reaching socio-economic impacts, including: 1) impact on sheltering especially on the elderly and on more vulnerable populations due to the lack of power (and therefore heat) and emergence of the cold weather front which is expected to last until Wednesday; 2) very high indirect economic costs as a result of dependency of industrial production on power supply and business disruptions; 3) impact on critical infrastructure such as hospitals where backup generators are not functioning (e.g., New York University's Tisch Hospital began evacuating more than 200 patients to other facilities, including 20 babies from neonatal intensive care, some of them on respirators operating on battery power[4]); 4) Impacts on nuclear reactors. Federal rules require that nuclear plants be shut down before any projected hurricane-force winds. Because reactors continue to generate potentially damaging heat well after fission has stopped, specially protected backup generators are required to ensure that cooling systems can continue to operate if there is a flood or loss of power. The Nuclear Regulatory Commission (NRC) reported that some nuclear power reactors in *Sandy*'s projected path had been closed for maintenance and others may be required to close. The agency dispatched inspectors to each facility ahead of the storm to make sure proper preparations and procedures were in place to assure safety.[5] So far no safety concerns from nuclear reactors has been reported, while ‘alerts’ (second lowest in a four-tiered warning system) were declared as water levels passed minimum levels a nuclear reactor in New Jersey.

Modeled Hurricane Power Outages:

Guikema and Quiring (2012) have developed a computer model looking at past hurricane events to provide estimates of power outages (defined as permanent loss of power to a set of customers due to activation of a protective device in the power system). The model is a hybrid of a classification tree and a semi-parametric generalized additive model (GAM), where the GAM estimates the number of customers that lose service in a given area if that area is predicted to have at least some service loss by the classification tree (Guikema and Quiring, 2012). Incorporating the actual track of *Sandy* as of 2 p.m. on October 29, 2012 (as well as the forecast beyond) the expected number of outages to occur to according to the model were estimated to be: *12-15 million people* predicted to lose power which can increase up to *19 million* depending on what happens in New York City (Guikema,

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[4] http://www.ctvnews.ca/world/flooding-power-outages-after-superstorm-sandy-batters-nyc-1.1016162#ixzz2Alz6QL87

[5] http://www.usatoday.com/story/news/nation/2012/10/29/hurricane-sandy-power-utilities/1666519/

2012a). In a media advisory update on October 30 fewer power outages than initially expected were predicted due to the weakening of Hurricane *Sandy*. The latest model prediction uses the last storm track and intensity forecast at 2 a.m. EDT on Tuesday, October 30 and puts the overall cumulative total at 8 to 10 million people at risk of power loss in the wake of the hurricane. In arriving at this figure it is important to note that the computer model predicts cumulative outages, not peak outages. Cumulative means the total count of anyone who has lost power, versus peak, which is the number of people without power at any one point in time. For instance, in Maryland, the local utility company reported approximately 290,000 cumulative power outages as of 10:30 a.m. on Monday, Oct. 29, but their peak was approximately 210,000 because they were actively restoring outages while new outages were occurring" (Guikema, 2012b).

Historic Events and Power Outages

The 2003 Northeast blackout spread through eight states and affected more than 50 million people but was not caused by a storm and did not involve downed power lines, broken trees and flooding. It lasted less than 24 hours for most people and was considered the second most widespread blackout in history. *Sandy*'s impact is expected to be less (on the order of 10 million people affected), however, power outages may last longer and linger on for days. In comparison to other hurricanes, the power outages from *Sandy* are expected to set records.

Table 4: List of historic events

Event	Number of people affected	Duration of Blackout
Opal (1995)	More than 2 million	Few days
Isabel (2003)	4.3 million	Few days
Katrina (2005).	More than 1.7 million	Repair lasted several weeks
Irene (2011)	7 million	Repair lasted several days to weeks in
2003 Northeast Power	55 million	Less than 24 hours
July 2012 India blackout	670 million	2 days

*List of power outages (Source: Wikipedia)

3.6 Indirect losses

Due to the storm, major business interruptions are expected in the manufacture sector, which can cause tremendous indirect losses for the US economy. The vulnerability of industrial pro-duction systems strongly depends on the type of industry, and can be determined with the help of vulnerability indicators (see Figure 16).

In general, production down times mainly occur due to the damage of production equipment, the obstruction of workers, the interruption of critical infrastructures or the disturbance of supply chain processes (e.g. delivery or distribution processes). Therefore, the industrial vulnerability strongly depends on the degree of dependency on capital, on labor, on infrastructure systems and on supply chain services. In order to operationalize these dependencies by indicators, quantifiable factors describing these dependencies have been identified.

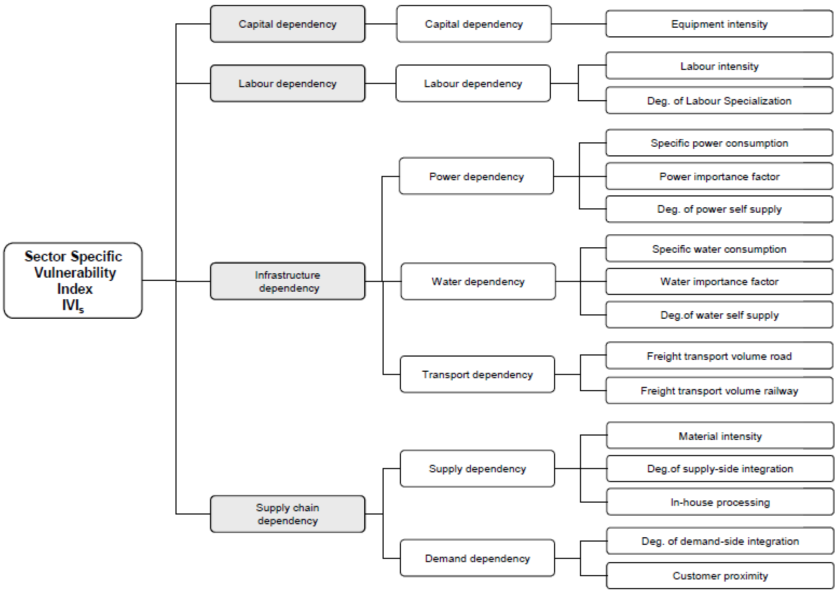

Figure 16: Sector Specific Vulnerability Index (Merz, 2011)

By considering the industrial density of regions (obtained through the value added) of the different sectors, it is possible to determine the industrial vulnerability against indirect disaster effects at the regional level (see Figure 17, right).

In this manner, the most vulnerable sectors against disruptions and failure of electricity supply and the transportation were identified. These were the basis for the construction of consequence scenarios, which depend on the

- duration and development of disruption
- vulnerability of the respective industrial sector S_i
- importance of S_i for the economy.

To consider the indirect cost in a systematic way, the scenarios were split in three parts considering the overall disruption due to the event (across all sectors), the impact of power blackouts, of the closure of stock exchange and the impact of disruptions of the transportation system.

The impact depends to a large degree on the assumptions about the recovery. Here, we provide results for just one scenario assuming that the disruptions of the overall manufacturing lasted for one day, the closure of the stock exchanges and offices affected 20 % of the finance sector, the duration of the electricity and transportation disruptions will be two and one week(s) respectively.

The total losses across all sectors are, under these assumptions, 39 bn US$ or 1,5 % of the GVA (see Figure 18).

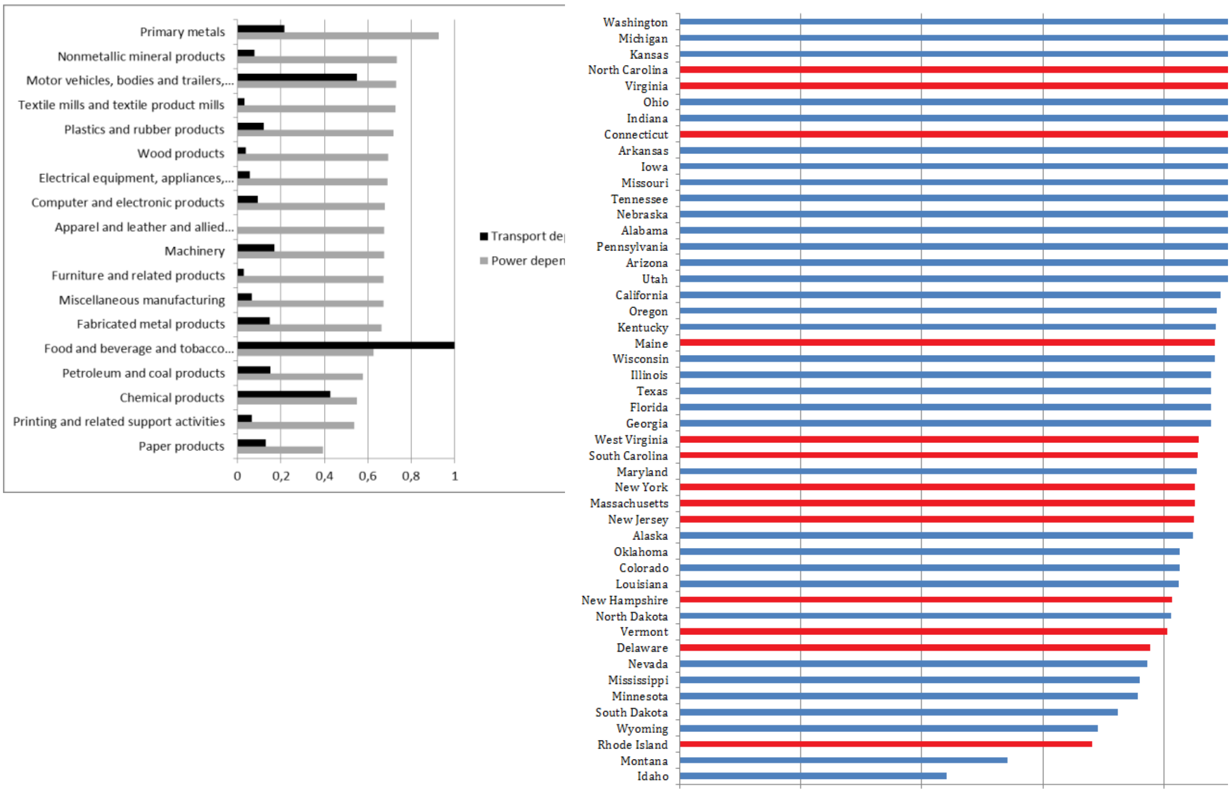

Figure 17: Dependency of manufacture sectors on power and transport (left); Industrial Vulnerability of US States against indirect disaster impacts (right)

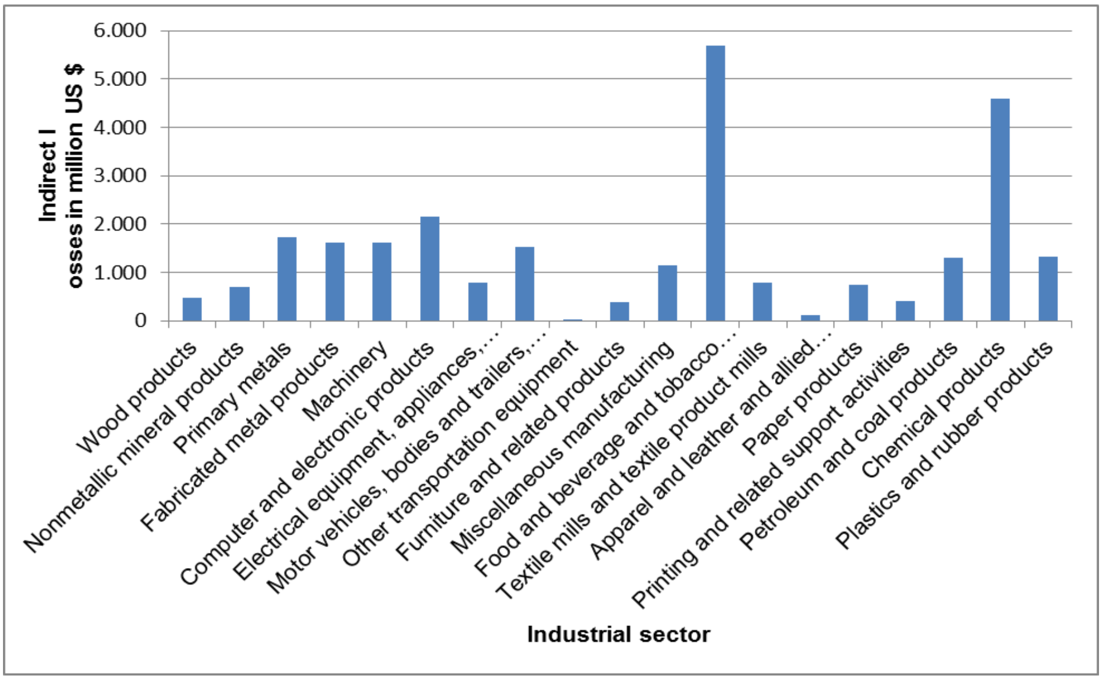

Figure 18: Indirect losses in industrial production

4 List of abbreviations

CEDIM FDA	CEDIM Forensic Disaster Analysis
CEDIM	Center for Disaster Management and Risk Reduction Technology
FDA	Forensic Disaster Analysis
FORIN	Forensic Disaster Investigations (IRDR Working Group)
IRDR	Integrated Research on Disaster Risk

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